Application of Forced Freeze during Flash-Butt Welding for Coil Joining of Advanced High Strength Steels (AHSS)

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Abstract

Recent improvements in control features and techniques for flash-Butt welding extend the range of high tensile strength steels weldable on conventional Flash-Butt Welding (FBW) machines. Many of these high tensile strength steels have high carbon equivalents, and have proven to be difficult to weld using the conventional FBW processes. A new technique termed "Forced Freeze" offers potential for joining AHSS grades in coil processing operations. Initial observations showed that use of Forced Freeze provided improvements in Olsen Cup Test results on a DP1180 grade of material. In this study, DP1180 steels flash-butt welded with and without Forced Freeze were assessed metallographically to provide interpretation if those Olsen Cup Test results. Interpretation of Forced Freeze suggests that combination of flash and resistance heating implicit in the approach provides flatter temperature profiles compared to conventional processing. Metallographic assessments showed that this resulted in more displaced metal on upset, a more localized upset, and a wider heat affected zone (HAZ) in the joint. These characteristics were interpreted to suggest that use of Forced Freeze provided higher bond line strains on upset, as well as reduced cooling rates after welding, potentially providing some auto-tempering to the joint microstructure. These factors are believed to have provided the improvements in Olsen Cup Testing seen with the use of Forced Freeze.

Introduction

Flash-Butt Welding (FBW) is a resistance welding process, employing current, time, and force to achieve solid state joints (Ref. 1). These three parameters are managed separately within the two major segments of the process: Flashing and Upset. During flashing, a voltage is applied across the ends of two work pieces. As the two work pieces are brought together over a fixed time, the resistance to current flowing through minute contact points on the faying surfaces generates Joule heating. This Joule heating results in both melting and expulsion of metal (flashing) as well as heat soak-back into the substrates. During the upset segment of the weld, a rapid application of force drives the molten surfaces into one another. This forging action results in residual molten material being expelled, and forging of the underlying solid metal. Additional heat may be applied as needed during the upset portion of the weld to both assist in forging and to control cooling.

Evolution of Control Features

Flash-Butt Welding has been available as a commercial technology for nearly 100 years. Early machines employed a long lever arm to advance a movable platen through the flashing region. A switch on the arm initiated the welding current. In such early flash-butt welding, the flashing motion was operator dependent and required great skill to produce good welds. Later, the lever arm was replaced with a motor driven cam to eliminate operator variability and to provide much greater upset force. The use of cams also facilitated different flashing profiles depending on the application. More recently, the advent of microprocessor based controllers (combined with hydraulic servo-valves) allowed further control of the welding profile. For example, a parabolic or exponential flashing profile could quickly be calculated in the motion controller in a few seconds. This provided greater flexibility and the benefit of increased uptime by eliminating the need to physically replace the cam when changing gauges and grades.

Modern Controls

Modern controls for FBW employ two main sub-systems which act synchronously as defined by the main processor. These include the Power Control and the Motion Control. The Power Control consists of a microprocessor based SCR contactor that regulates the welding current. SCR control essentially allows switching the power on and off, as well as fine regulation of the voltages provided to the transformer. In addition, the power control also provides the ability to switch the transformer High – Low windings during the weld. Further, the main processor allows the series tap switch to be changed automatically, but not during welding.

The Motion Control defines the time dependent positioning of the movable platen. This includes several key components as shown in Figure 1: 1) a processor to generate the motion profile, 2) hardware to provide an analog signal to the hydraulic proportional valve, 3) a hydraulic cylinder, and 4) a feedback device that provides the actual position of the movable platen.

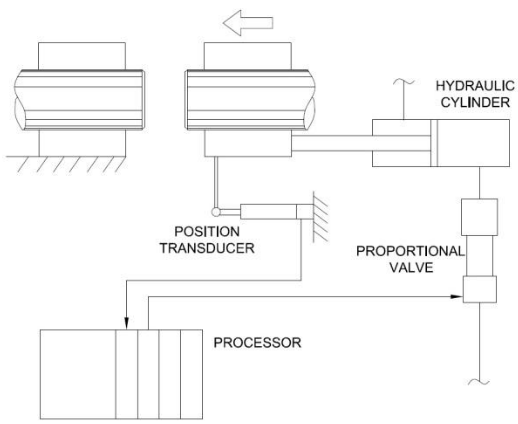

Figure 1. Block Diagram of a Computer Controlled Hydraulic System for Flash-Butt Weld Platen Motion.

Figure 2 shows the platen position and weld current relationship throughout the entire weld. Key points of each segment are describes as:

1) Linear Ramp: In this segment, the platen moves with a constant velocity from the load position to the initial die position. Flashing is initiated at high voltage at this time.
2) Flashing Segment: During this portion of the process, sufficient voltage is applied to allow uniform expulsion of metal during individual contacts without butting or shorting. Typically, this voltage is kept as low as possible to prevent excessive expulsion and the potential for oxide inclusions. The platen follows the flashing curve as calculated by the processor. Flashing is intended to create a temperature distribution in the workpieces similar to that shown in Figure 3.
3) Upset: At the end of the flashing cycle, metal on both sides of the contacting surfaces has been heated in excess of the forging temperature. Upset ensues as the platen rapidly moves forward, forging the parts together. Upset is often accompanied by additional current to facilitate forging.

4) Temper: In some cases the weld may be tempered by passing pulses of current through the joined material.

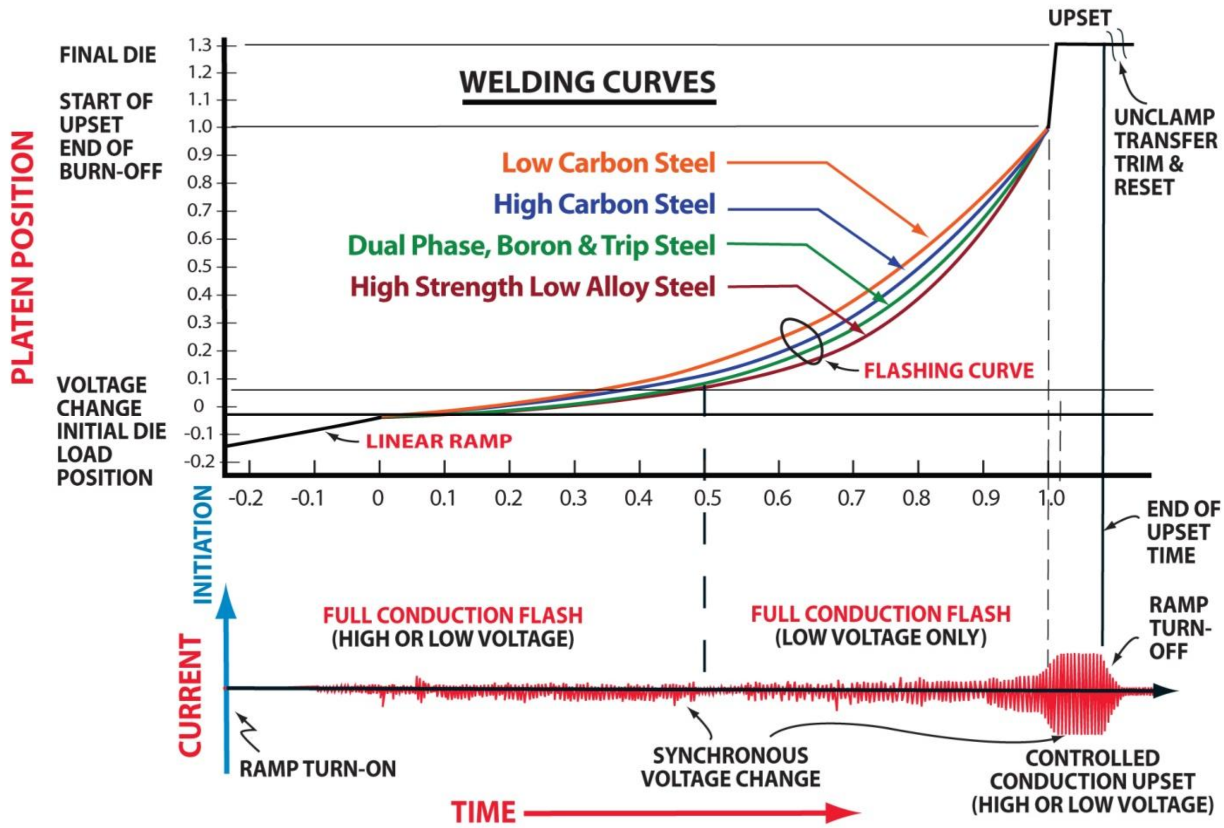

Figure 2. Flashing Curves and Current

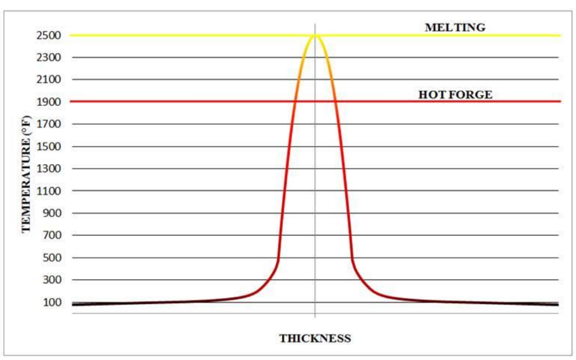

Figure 3. Schematic Representation of Temperature Gradient in the Workpieces at the Start of Upset

Forced Freeze

Forced Freeze is a new technique developed and patent pending (Ref. 2) at Taylor-Winfield Technologies augmenting the basic flash-butt welding cycle. Forced Freeze is demonstrated schematically in Figure 4 below. Forced Freeze consists of a controlled rapid platen advance near the end of the flashing segment. The amount of platen offset and when it occurs are both variables in the approach.

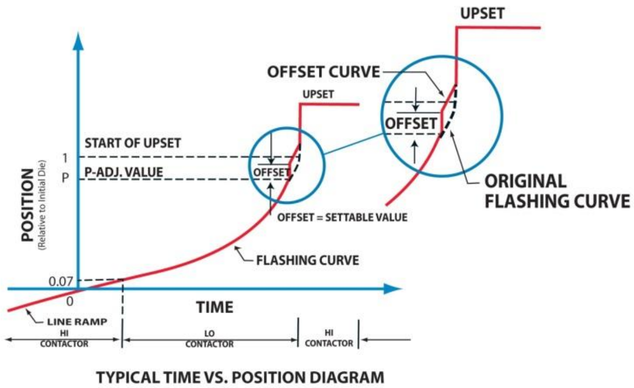

Figure 4. Modification of the Flashing and Upsetting Profiles to Accommodate the Forced Freeze Method.

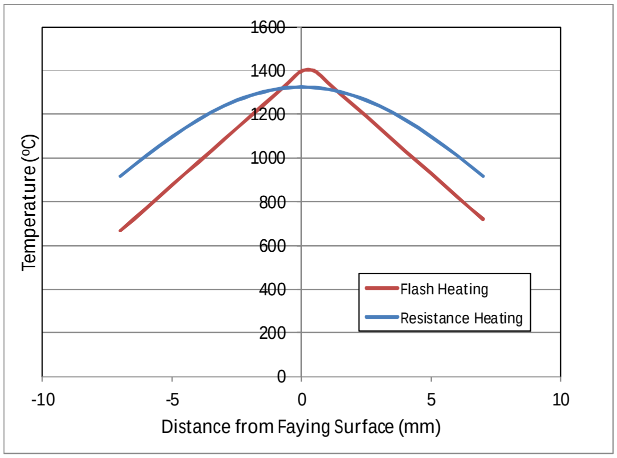

Figure 5. Comparison of the Calculated Temperature Distributions for Flash and Resistance Heating. Calculations are based on a final die opening of 11-mm and a flashing time of 6-s.

Forced Freeze effectively allows a change in the mechanism of heating at the transition point between flashing and upsetting. Prior to the initiation of Forced Freeze, heating of the steel is caused by flashing at the interface, with subsequent conduction into the workpieces. With the initiation of Forced Freeze, the flashing interface is eliminated, the effective current increases, and heating is now due to the resistance of the workpieces themselves. The implication of this change in heating mechanism is diagramed in Figure 5. The results shown are from one-dimensional modeling of flash-butt and upset butt processes. For flashing, it is clear that the temperature is highest at the faying (flashing) surface, and drops rapidly away from this location. For resistance heating, the thermal profile is delocalized. This is due to the fact that all locations along the workpiece contribute to this resistance heating. The Forced Freeze process then incorporates both of these mechanisms. The result, however, is a more uniform heat distribution between the dies prior to upsetting.

<u>Application of Forced Freeze for Flash-Butt Welding a Candidate Advanced High Strength Steel (AHSS).</u>

In this study, the effect of Forced Freeze on the flash-butt weldability of a candidate AHSS was evaluated. The material studied was a DP1180 steel, nominally 1.65-mm thick. A dedicated flash-butt welding system at Taylor-Winfield Technologies was used in these studies. The steel was welded at a nominal 500-mm strip width. Welding conditions used are provided in Table 1. Evaluations at the welder using Olsen Cup Testing showed that those with Force Freeze passed, while those without did not. To interpret this behavior sample welds with and without Forced Freeze were then sectioned and subject to metallographic inspection and microhardness evaluation.

Table 1 – Nominal Conditions for Flash-Butt Welding used throughout this Study.

Initial Die (mm)	Final Die (mm)	Upset (mm)	Flash Off (mm)	Upset Time (ms)	Upset Heat (%)	Flash Time (seconds)	Flashing Profile
18.16	8.38	2.67	7.11	66.7	90	6	Logarithmic

Macrographs of the welds made with and without Forced Freeze are presented in Figures 6 and 7. Differences in welds made with and without Forced Freeze were characterized by two features. First were the geometric characteristics of the upset material itself. Welds with Forced Freeze showed a volume of solid/semi-solid material in the extruded flash, and a relatively sharp curvature of the metal in the upset region compared to those made with standard processing. Secondly, welds with Forced Freeze show heat affected zone widths 10% to 20% larger than those made without the method.

Bond line microstructures from the bond line regions of these two representative welds are provided in Figures 8 and 9. Microstructures from the two welds are metallurgically quite similar. Both welds show highly acicular microstructures characteristic of martensite. Of interest, both welds also show some evidence of micro-porosity, not seen farther away from the bond line. These micro-pores are typically related to constitutional liquation at grain boundaries, and are an artifact of the proximity to the (molten) flashing surface prior to upset.

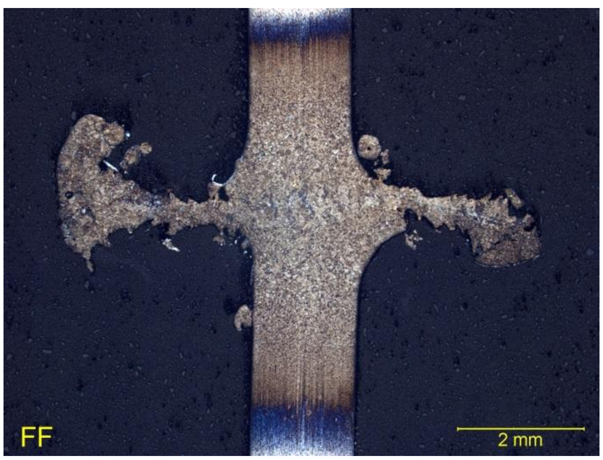

Figure 6 – Macro-section of a Flash-Butt Weld on DP1180 Steel made with Forced Freeze.

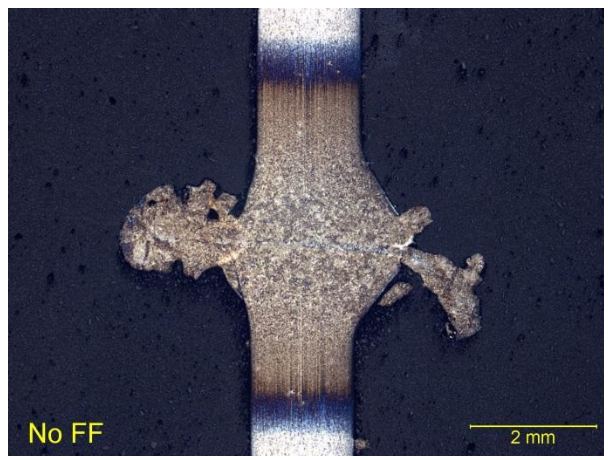

Figure 7 – Macro-section of a Flash-Butt Weld on DP1180 Steel made without Forced Freeze.

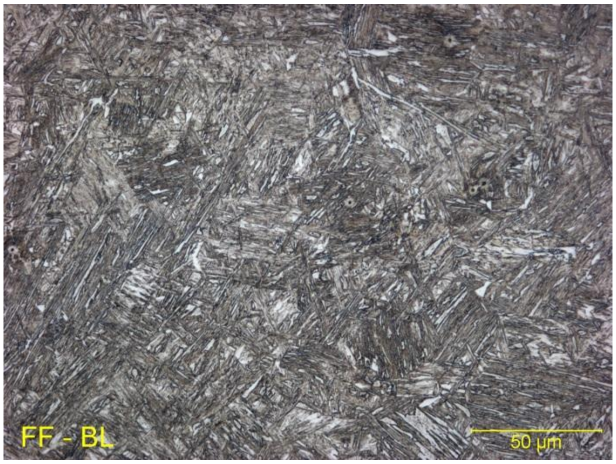

Figure 8 – Bond Line Microstructure for the Flash-Butt Weld made using Forced Freeze.

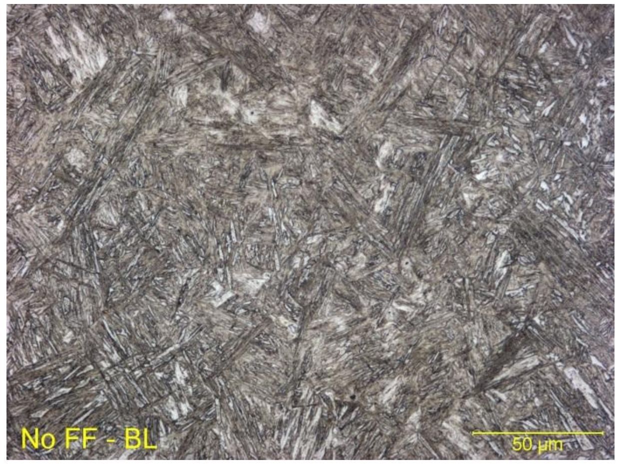

Figure 9 – Bond Line Microstructure for the Flash-Butt Weld made without Forced Freeze.

Hardness profiles for these welds are provided in Figures 10 and 11. The profiles are in many ways similar. Both show a relatively flat profile across the entire HAZ/bond line region. Both samples show peak hardnesses in at or near 500-VHN, suggesting martensitic microstructures. Both samples show a loss in hardness at the bondline itself. This effect has been described previously, and is associated localized decarburation during flashing. The hardness profiles differ in two ways. First, the extent of the hard zone is different. That for the weld made in the conventional way is roughly 1-mm narrower than when Forced Freeze is employed. Second, it appears that there is a shift in average hardness between the two welds. For reference, a line representing 500-VHN is superimposed on both profiles. The weld made without Forced Freeze is seen to achieve that level regularly across the transformed region. Alternately, the weld made with Forced Freeze shows (with one exception) hardnesses below that 500-VHN level.

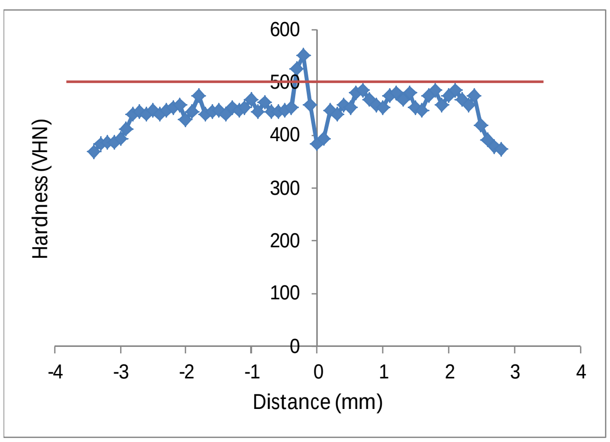

Figure 10 – Hardness Profile taken from the Flash-Butt Weld using Forced Freeze.

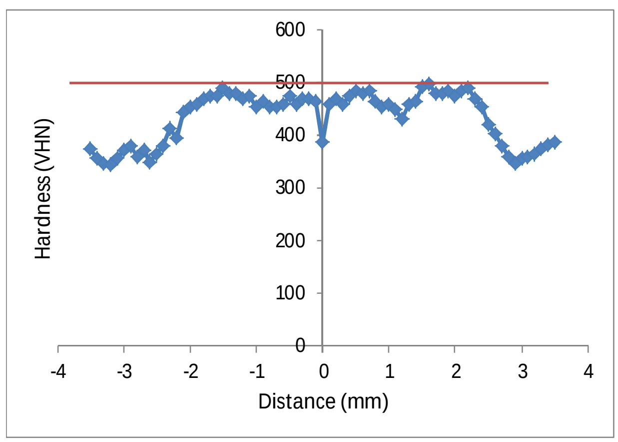

Figure 11 – Hardness Profile taken from the Flash-Butt Weld made without Forced Freeze.

As mentioned previously, the work conducted in this study was intended to interpret the apparent benefit of using Forced Freeze for the flash-butt welding of a DP1180 AHSS based on Olsen Cup Testing. The interpretation of the process suggests that by providing a component of non-upset associated resistance heating, that flatter temperature profiles could be achieved during flash-butt welding. Implications of these flatter temperature profiles can be seen from every aspect of this analysis. Flatter temperature profiles of course imply wider forge zones at the initiation of upset. These larger forge zones provide a greater volume of material to be extruded on upsetting. This was clearly observed in the macro-sections shown. In addition, since upsetting is done to a fixed distance, flatter temperature profiles suggest a larger volume of material will be available above the forging temperature to be extruded, resulting in the steeper flash profile. Conversely, when using displacement controlled upsets, materials with a steeper temperature profile will quickly expel material above the forging temperature, due to engaging colder and higher flow strength metal. The result is the type of reduced flash delocalized upset observed. The former case (with Forced Freeze) can then result in higher deformations during welding, achieving improved quality joints. The change in temperature profile is also evident in the extents of HAZ's observed. Clearly, the flatter temperature profile (with Forced Freeze) resulted in wider metallographic HAZ's and broader apparent transformed zones in the hardness traces. Of interest is the apparent slight drop in hardness in the Forced Freeze welds. It is possible that the flatter temperature profiles minorly affect the cooling rates, and as a result cause a small amount of auto-tempering in the transformed region. Such a small amount of auto-tempering would increase the local toughness of the transformed material and thus apparent performance.

It appears then, that three factors contribute to the observed improvements in performance associated with Olsen Cup Testing Forced Freeze processed welds. These include:

(1) Increasing bond line strains and thus weld quality
(2) Widening the transformed region thus delocalizing loading during testing
(3) Auto-tempering resulting from the slower cooling rates, facilitating improvements in toughness.

These observations suggest that use of Forced Freeze can be beneficial for joining AHSS and other hardenable steels in coil processing operations.

Conclusions

Forced Freeze is a Taylor-Winfield Technologies' patented technology offering changes to how heating and upsetting is accomplished in flash-butt welding. Force freeze results in flatter temperature profiles compared to conventional flash butt welding practices. Recent efforts showed that Forced Freeze could be beneficial for coil joining AHSS in steel processing operations. This study was conducted to provide some metallurgical underpinnings to these apparent benefits. Sample flash-butt welds with and without Forced Freeze were sectioned and examined metallographically. Results showed that the flatter temperature profiles implicit in the combination of flash and resistance heating when using Forced Freeze resulted in greater volumes of extruded flash on upset, as well as sharper curvatures at the root of the flash curl. These observations suggest greater bond line strains are achieved with Forced Freeze, and thus better bonding quality. In addition, Forced Freeze resulted in deeper heat penetration into the substrates. This appeared to both delocalize loading in the hardened areas of the weld, and potentially provide reduced cooling rates enabling some small amount of auto-tempering. This combination of features is believed to provide better quality welds, permitting successful Olsen Cup Testing at the welding machine.

References

2003. RWMA Resistance Welding Manual, Revised Fourth Edition, RWMA, Miami, FL.

(1) Matteson, R. P. 2012. Forced freeze welding of advanced high strength steels. US Patent Application US 20120305533 A1.